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Use of remote sensing to measure change in the extent of habitat for the critically endangered Jerdon's Courser *Rhinoptilus bitorquatus* in India

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Jerdon's Courser *Rhinoptilus bitorquatus* is one of the most endangered and least understood birds in the world. It is endemic to scrub habitats in southeast India which have been lost and degraded because of human land use. We used satellite images from 1991 and 2000 and two methods for classifying land cover to quantify loss of Jerdon's Courser habitat. The scrub habitats on which this species depends decreased in area by 11–15% during this short period (9.6 years), predominantly as a result of scrub clearance and conversion to agriculture. The remaining scrub patches were smaller and further from human settlements in 2000 than in 1991, implying that much of the scrub loss had occurred close to human population centres. We discuss the implications of our results for the conservation of Jerdon's Courser and the use of remote sensing methods in conservation.

Globally, habitat loss and fragmentation are major threats to the continued survival of many species (Fahrig 1997, Huxel & Hastings 1999, World Resources Institute 2001). Quantifying rates of habitat loss is a vital step in understanding and prioritizing the threats facing species in different ecosystems. This is particularly important for endemic species, which often depend upon special habitats and are thus at greater risk of extinction through habitat degradation (Brooks *et al*. 2000, Norris & Harper 2004).

Jerdon's Courser *Rhinoptilus bitorquatus* occurs only in India and is listed as Critically Endangered by the IUCN (IUCN 2006). This nocturnal species was first described in 1848 and subsequently recorded sporadically until 1900. It was then not seen again until 1986 (Bhushan 1986). The species is known to inhabit open patches within scrub jungle bordering dry deciduous forests (Bhushan 1986) and, since its rediscovery, it has only been seen in a few restricted areas in the Cuddapah district of Andhra Pradesh, India (Jeganathan *et al*. 2004). Its known range is very small and it is believed to have a small and possibly declining population (BirdLife International 2001).

Jerdon's Courser can be detected using playback surveys to elicit calls (Jeganathan & Wotton 2004) and tracking strips to record footprints (Jeganathan *et al*. 2002). These methods have provided firm evidence of the presence of the species in a few small areas. However, there is virtually no information available about the behaviour or population ecology of the species. Nevertheless, a study of habitat use using tracking strips has identified the preferred habitat as scrub jungle with open areas where the density of large bushes (> 2 m tall) is in the range 300–700 ha^{-1} and the density of small bushes is < 1000 ha^{-1} (Jeganathan *et al*. 2004).

Although further studies are in progress, comprehensive population size and distribution data do not exist, individuals are rarely seen and no nest has ever

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been found. Inventories and maps of the preferred habitat of a species are required not just to improve ecological knowledge, but also as a prerequisite for developing a conservation management plan (Gurnell *et al.* 2001, Gibson *et al.* 2004). Given the lack of information on Jerdon's Courser, quantifying changes in the scrub habitat of this region is a high priority for planning and implementing a conservation strategy.

The state of Andhra Pradesh in India has seen the growth of intensive agricultural practices in recent years, with crops such as rice, sugarcane, groundnut, citrus and cotton becoming more common. The impact of these changes on scrub habitat is difficult to assess because detailed landscape survey data are not available. Advances in GIS and remote sensing have helped ecologists to assess the influence of the spatial configuration of habitat on ecological processes (Scott *et al.* 1993, Johnston 1998, Millington *et al.* 2002). These techniques allow rapid assessments of large, often remote or inaccessible areas and the changes occurring within them. Remote-sensing and GIS techniques have been used in a wide range of ecological studies, including assessments of changes in biodiversity (Roy & Tomar 2000, Nagendra 2001), land cover (Franklin *et al.* 2000, Saveraid *et al.* 2001), ecological variations due to climate change (Kerr & Ostrovsky 2003) and habitat loss (Scott *et al.* 1993).

Ground-based surveys for monitoring changes in distribution and abundance of species and habitats are labour-intensive and can generally only be applied to small geographical areas and selected taxa. The use of digital data from Earth-orbiting satellites offers the potential for rapid surveys of land cover (Cherrill & McClean 1995) and several studies have successfully used remote-sensing techniques to answer ecological questions related to habitat suitability of several bird species (Osborne *et al.* 2001, Saveraid *et al.* 2001, Hill *et al.* 2004, Boyle *et al.* 2005). In this paper, we report the use of satellite imagery to detect recent change in the extent of suitable habitat for Jerdon's Courser and to identify alterations in land use driving these changes.

METHODS

Study area

The study was conducted mainly in the Cuddapah district and parts of the Nellore district in Andhra Pradesh, India. The focal point of the study was the Sri Lankamaleshwara Wildlife Sanctuary (SLWS) and neighbouring areas in the valley of the river Sagileru (14°N, 79°E), where Jerdon's Courser was rediscovered in 1986 (Fig. 1). This remains the only part of the district from which confirmed reports of the species have been obtained since 1986. The Wildlife Sanctuary was designated by the Andhra Pradesh Forest Department primarily to protect Jerdon's Courser.

Satellite imagery

Two satellite images of the study area obtained in 1991 and 2000 were used to quantify changes in land cover during that period. The earlier image was a geo-referenced Landsat 5 Thematic Mapper (TM) taken on 24 April 1991 and the latter a geo-referenced Landsat 7 Enhanced Thematic Mapper (ETM+) taken on 6 December 2000. Each of the images covered an area of 180 × 175 km. These images were chosen

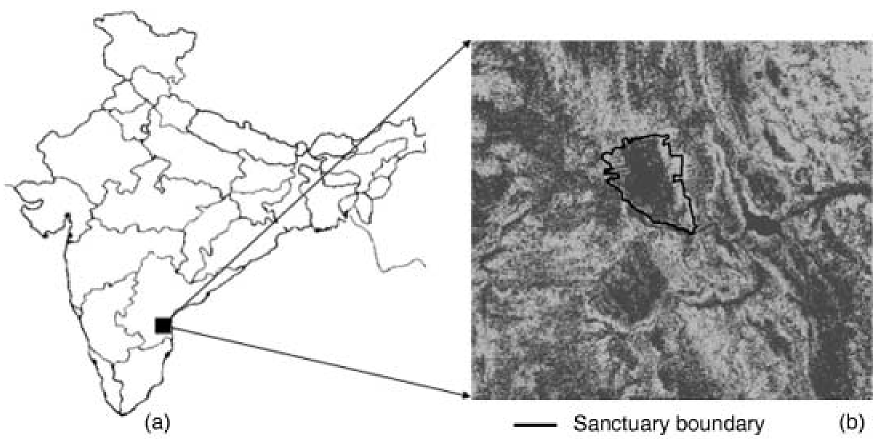

Figure 1. Map of India showing (a) the study area and (b) the location of the Sri Lankamaleshwara Wildlife sanctuary within the study area.

because they had little or no cloud cover, the time interval between them was long enough to reveal significant change, and they were taken during the dry season when key landscape features can be clearly distinguished (Batistella 2001, Jeganathan *et al.* 2004).

The images were already radiometrically and geometrically corrected when acquired. They were converted into image files in order to enable further analysis. As the area of interest comprised a smaller rectangular region within this large section, a subset was produced from each image which covered an area of 120 × 110 km. The coordinates of the southwestern and northeastern corners of this rectangle were 14.0°N, 78.2°E and 14.5°N, 79.3°E, respectively. False-colour composites (FCCs) of satellite data were produced using the visible green, visible red, and near- and mid-infrared bands. The pixel size of the FCC was 28.5 × 28.5 m.

Classification of satellite imagery

Land use land cover (LULC) maps were produced for both the 1991 and the 2000 images using both hard and fuzzy classification. Land cover refers to those types of features present on the surface of the Earth which can be identified by remote sensing, and land use refers to the human activity or economic function associated with a specific piece of land. For image analysis, ERDAS Imagine for Windows (version 8.7) was employed throughout.

The hard classification LULC maps were produced using the supervised classification method of spectral pattern recognition (Lillesand & Kiefer 2000), in which the analyst specifies numerical descriptions of the various LULC categories present in a scene to the software algorithm. Classification was based on the maximum-likelihood parametric rule, which is the probability of a given pixel value being a member of a particular LULC category. The output consisted of thematic maps containing the eight LULC classes (agriculture, deciduous forest, human habitation, open areas, rocky areas, sandy areas, scrub and water bodies). The agriculture class included all areas planted with crops such as rice, lentils, sugarcane, groundnut and sunflower as well as citrus orchards within the study area. The open areas included naturally open areas, pasture land with very short grass and areas cleared for agriculture but not yet planted with crops.

A limitation of the maximum-likelihood method of classification is that it assigns LULC classes to each individual pixel without reference to the classification of the surrounding pixels, which can decrease the overall accuracy of the classification (Lo & Choi 2004). The scale of the image, as well as its spatial and spectral characteristics, can influence the accuracy of the classification and can give rise to the problem of mixed pixels (Tso & Mather 1999). For these reasons a soft classifier based on fuzzy logic, i.e. logical processing using fuzzy sets (Klein 1998), was used to improve the overall accuracy of the hard classification. Fuzzy set theory provides useful concepts and methods to deal with uncertain information, and uses the vagueness in the boundaries between classes to classify cells in a context-specific manner (Hegde 2003).

Fuzzy classification was implemented using the fuzzy k-means approach (Lillesand & Kiefer 2000). This involves using spatial filtering by passing a square window (3 × 3, 5 × 5 or 7 × 7 pixels) over the surface of the image and computing a new value of the central cell of the window (Lillesand & Kiefer 2000). This has the effect of creating a context-based classification in which the problem of speckling (i.e. individual pixels differing in classification from their immediate surroundings) is reduced.

Ground-truthing satellite images

Ground-truthing of the most recent (2000) satellite image was carried out in April 2004 using a Garmin eMap and eTrex Global Positioning System (GPS) receiver with positional accuracy of 10–15 m. The points for ground-truthing were selected at random within each of the eight LULC classes, but the sampling fraction was higher for some classes (e.g. scrub) than others. In total, 544 points were visited and satisfactory data were available for 500 points. Coordinates were recorded in Universal Transverse Mercator (UTM) units, to which the satellite images were also geo-referenced.

Quantifying changes in land use and land cover

The area covered by each LULC category in 1991 and 2000 was determined by multiplying the number of pixels classified in each class by the pixel size. The net loss or gain in the area over time for each class was then calculated. In order to assess what type of changes had occurred during this time period, the LULC classification of a random sample of 5000 points, generated using ERDAS Imagine, was compared between 1991 and 2000.

Assessing accuracy of classification

In order to assess the accuracy of classification, an error matrix was compiled using the accuracy assessment option in the ERDAS Imagine software (Lillesand & Kiefer 2000). This matrix compared the relationship between known reference data (ground-truth) and the corresponding results of the supervised classification for 500 locations, on a category-by-category basis. As ground-truth information was not available for 1991, this could only be done for the 2000 image. For each LULC class, the algorithm generated a producer's accuracy (i.e. the level of accuracy of the training set pixels) and a user's accuracy (i.e. a measure of commission error indicating the probability that a pixel was correctly classified (Lillesand & Kiefer 2000)). In addition, the overall classification accuracy was calculated and a kappa statistic (κ) was generated for each LULC class.

Misclassification of pixels would be expected to bias the estimate of the change in the extent of scrub, so we made an adjustment for this. Suppose that a proportion A_S of the pixels classified as scrub on the satellite image actually had land cover of scrub vegetation. The proportion of all pixels classified as being of LULC classes other than scrub that actually had land cover of scrub is taken to be A_{NS}. Let the observed proportion of pixels that are classified by analysis of the remote sensing data as scrub be S_O. Then the true proportion of the area which is covered by scrub S_T is given by

$$S_T = A_S S_O + A_{NS}(1 - S_O).$$

If we assume that the April 2004 field surveys represent ground-truth for the December 2000 image, then A_S can be taken to be the proportion of ground-truthed pixels classified from remote-sensing data, using the hard classification, as scrub that were observed to have scrub vegetation on the ground-truth visit: 132/223 = 0.5919. The crude proportion of all pixels classified as being of LULC classes other than scrub that actually had land cover of scrub during the ground-truth survey was 27/255 = 0.1059. However, this proportion varied among the seven non-scrub LULC classes between 0 and 0.2632. As LULC classes were not ground-truthed in proportion to their abundance, a weighted mean of these LULC-specific proportions was calculated in which the weights were the numbers of pixels of each non-scrub LULC class in the 2000 image expressed as a proportion of the sum of all non-scrub LULC pixels. This weighted mean value of A_{NS} for the 2000 image was 0.0976. The equivalent weighted mean of the same proportions, but with weights derived from the 1991 image, gave an A_{NS} value of 0.1236 for the 1991 image. We estimated S_T for each image date using the expression given above, the observed value of S_O and the estimates of A_S and A_{NS}.

Determining changes in scrub habitat

In order to illustrate changes in the area of scrub habitat of Jerdon's Courser, the LULC maps produced for 1991 and 2000 were reclassified to show only the areas covered with scrub. Changes in the area and spatial distribution of scrub habitat between these two time periods were then assessed and an image generated to show areas where changes in scrub had occurred and also areas of no change.

In addition, the sizes of two different 50 randomly selected scrub patches in 1991 and 2000 were compared. To determine what had replaced the scrub habitats, the LULC class in 2000 was determined for 5000 randomly selected points that were classified as scrub in 1991. For this analysis, the open ground, rocky terrain and sandy areas were all classified into one category as bare ground.

Effect of human settlements on scrub

In order to assess the impact of human settlement on scrub patches, the distances from a random sample of 100 villages to both the nearest scrub patch and the nearest agricultural land were measured in 1991 and 2000 for the same villages.

RESULTS

Changes in land use and land cover

The land cover classification for 1991 and 2000 (Figs 2 & 3) clearly indicates that large areas of scrub have been lost in the northwest of the study area and that fragmentation of scrub habitats has occurred elsewhere, particularly in the northeast. Calculations from the hard classification of the area covered by each LULC class for 1991 and 2000 (Table 1) showed that 14.4% of scrub had been lost within this 10-year period, while the area occupied by agricultural land more than doubled (109% increase) during the same period. The fuzzy classification using 3×3, 5×5 and 7×7 pixel filters estimated the scrub loss within the study area to be 11.2, 12.6

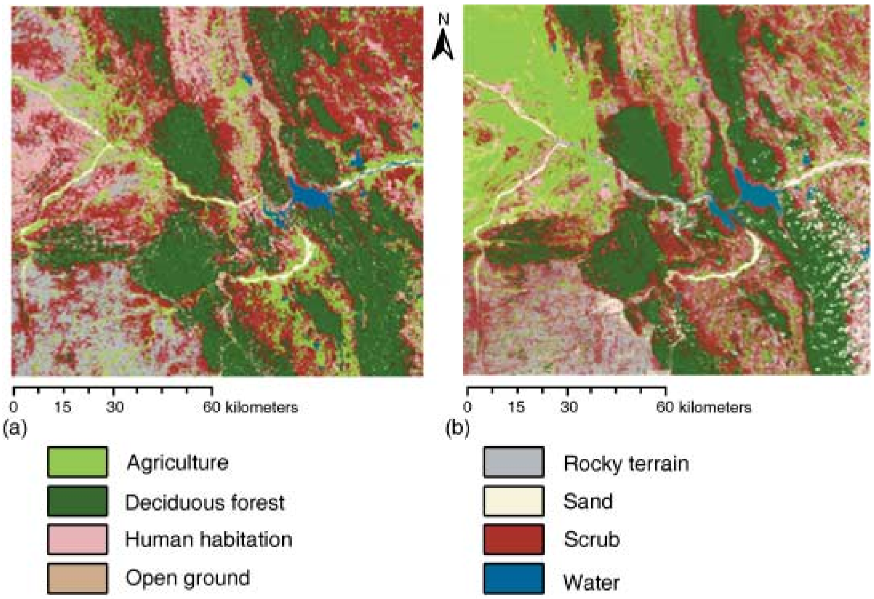

Figure 2. LULC maps obtained using the hard classification for the years (a) 1991 and (b) 2000, showing the eight categories used for classification of the study area.

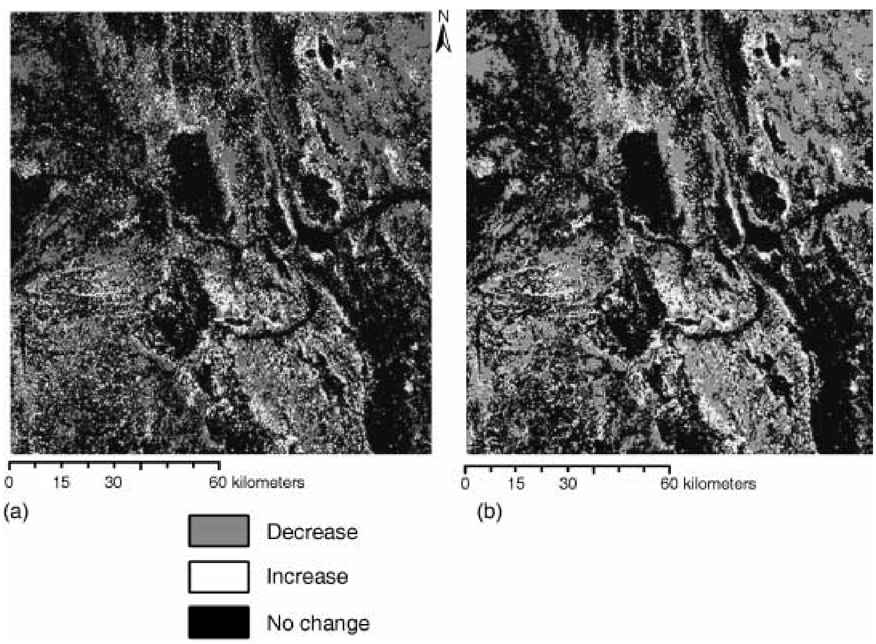

Figure 3. Maps of change in scrub habitat between 1991 and 2000 in the Cuddapah and Nellore districts, Andhra Pradesh, India, generated using (a) hard classification and (b) fuzzy classification of remote-sensing images showing areas where the scrub has increased, decreased and areas showing no change.

and 15.0%, respectively. After adjusting for the classification errors of scrub and non-scrub habitats as described in the Methods, the mean net loss of scrub was 14.6%.

Between 1991 and 2000, there have been significant non-random changes in patterns of land use in the region (Table 2, $\chi^2_{49} = 7591.71$, $P < 0.001$). As shown in Table 2 the loss of scrub habitats is principally the

Table 1. Changes between 1991 and 2000 in the area of eight types of land use or land cover from a hard classification of a 13 200-km^2 area of Cuddapah and Nellore districts, Andhra Pradesh, India.

Land cover type	Area in 1991 (km^2)	Area in 2000 (km^2)	Change (km^2)	Percentage change
Scrub	4495	3847	−648	−14.4
Deciduous forest	3419	3010	−409	−12.0
Human settlement	1542	1222	−320	−20.8
Rocky terrain	1211	974	−237	−19.5
Open ground	992	883	−109	−11.0
Water	152	192	+40	+26.0
Sand	144	576	+432	+300.0
Agriculture	1155	2411	+1256	+108.7

Table 2. Changes in land use or land cover classification between 1991 (rows) and 2000 (columns) of 5000 randomly selected pixels from the satellite images of the study area within Cuddapah and Nellore districts, Andhra Pradesh, India.

	Agriculture	Deciduous forest	Human habitation	Open ground	Rocky terrain	Sand	Scrub	Water	Total no. of pixels in 1991
Agriculture	208	31	65	12	11	11	108	9	455
Deciduous forest	36	832	23	1	6	36	307	0	1241
Human habitation	261	66	123	16	2	5	115	5	593
Open ground	90	9	58	82	43	27	82	4	395
Rocky terrain	98	6	15	41	187	9	117	0	473
Sand	1	0	1	0	1	77	3	7	90
Scrub	324	136	131	135	92	60	767	4	1649
Water	3	2	16	1	2	4	7	69	104
Total no. pixels in 2000	1021	1082	432	288	344	229	1506	98	5000

result of conversion to agricultural land (324 pixels), whereas the gains in scrub habitat have largely been at the expense of deciduous forest (307), most probably as a result of forest clearance and fires. Large areas of open ground and rocky terrain have also undergone conversion to agriculture (Table 2).

Accuracy of classification

The overall classification accuracy for the 2000 LULC map was 58.8% for the hard classification ($\kappa = 0.46$). For the fuzzy classification with three different window sizes (3×3, 5×5 and 7×7 pixels), the overall classification accuracy values were 59.7, 55.4 and 53.0% ($\kappa = 0.49$, 0.40 and 0.39, respectively). For the eight LULC classes, the producer's accuracy ranged from 42.1 to 100% and the user's accuracy ranged from 42.1 to 100%, while the κ statistics ranged from 0.38 to 1 where a value of 1 denotes 100% accuracy. The waterbodies had 100% classification accuracy while other LULC classes showed lower levels of classification accuracy, often due to indistinct borders between classes.

Changes in distribution and patch size of scrub habitat

Detection of change in the location of scrub using both the hard classification and the fuzzy classification with a 3×3 filter shows the areas within the study area where scrub has significantly decreased or increased (Fig. 3). Decreases occurred in 35% of the study area, whereas increases occurred in 15% of the study area.

The mean area of scrub patches decreased significantly from 24.2 km^2 (±2.9, $n = 50$) to 9.3 km^2 (±1.1, $n = 50$) between 1991 and 2000 ($t_{98} = 4.16$, $P < 0.001$). This represented a decrease of 38.4%, and conversion to agriculture and cleared areas (open ground) were the main cause of scrub loss (Fig. 4).

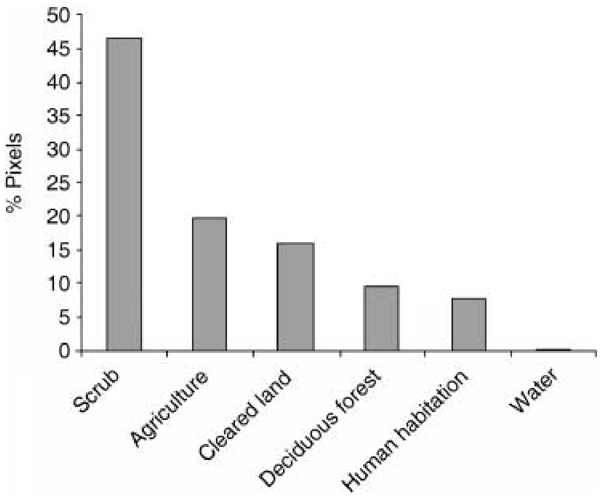

Figure 4. Land use classification in 2000 of cells classified as scrub in 1991 in the study area within the Cuddapah and Nellore districts, Andhra Pradesh, India.

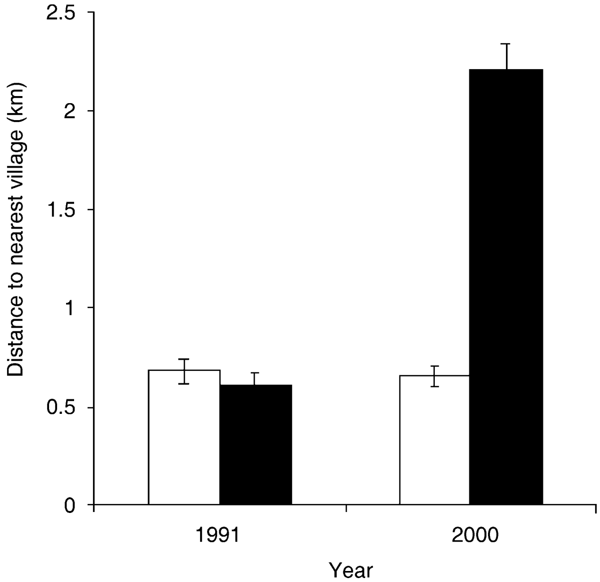

Figure 5. Mean (± se) distances from 100 villages to the nearest agricultural land (open bars) and scrub patch (filled bars) in 1991 and 2000, in the Cuddapah and Nellore districts, Andhra Pradesh, India.

Change in the proximity of scrub to human settlements

The mean distance between villages and the nearest scrub patch increased significantly between 1991 and 2000 (t_{198} = 11.13, $P < 0.001$, Fig. 5). However, the mean distance from the villages to the agricultural land did not change over this period (t_{198} = 0.34, ns).

DISCUSSION

India's biodiversity is under extreme pressure as a result of high human population densities and consequent rapid rates of habitat loss and degradation (Roy & Tomar 2000). The spread of agriculture and associated irrigation schemes into arid areas is very likely to degrade biodiversity further (Narumalani *et al.* 2004), but the remoteness of many of these locations makes assessments of these changes difficult.

Satellite-based remote-sensing applications in conservation have been in place for more than 30 years, and are especially required for remote regions of the world that are difficult to access but where information is urgently needed (Gottschalk *et al.* 2005). Although remote-sensing studies of bird conservation and ecology have taken place all over the world (Osborne *et al.* 2001, Saveraid *et al.* 2001, Gibson *et al.* 2004, Hill *et al.* 2004, Jeganathan *et al.* 2004, Venier *et al.* 2004, Boyle *et al.* 2005, Bradbury *et al.* 2005), research in the tropical regions accounts for only about 10% of these studies (Gottschalk *et al.* 2005).

The remote-sensing approach employed here to quantify changes in Jerdon's Courser habitat indicates rapid and extensive declines in scrub, with approximately 495–674 km^2 of scrub (11–15%) lost from an area of over 13 200 km^2 between 1991 and 2000. This is an annual rate of loss of 1.2–1.7%. Adjustment of the rate of loss for the effect of errors in classification made very little difference to the estimates. The majority of these changes can be attributed to the widespread expansion of land use for agriculture, which is the main occupation of people living within the area. Patch size of scrub habitat has declined significantly in the last decade and the irrigation required to sustain agricultural activities is likely to fragment the remaining habitat further. These changes are likely to threaten seriously the tiny remaining population of the critically endangered Jerdon's Courser, which is only known to occur in a small area of scrub jungle within this region (Jeganathan *et al.* 2004).

In addition to losses of scrub habitat, substantial areas of forest and open land are also being converted into agricultural land. If this trend continues, it is very likely to have a serious impact on other species living within the area. Although the overall loss

of scrub habitat has been dramatic in this very short period of time, Table 1 also shows pixels that were classified as having changed from other land cover categories into scrub and vice versa. Shrubs regenerate rapidly on land cleared of scrub for grazing if it is left undisturbed with only light grazing (P. Jeganathan and R.E. Green pers. obs.). This is probably what resulted in the change from rocky areas and open patches into scrub. Change from scrub to water could be a result of temporary pools formed due to rain when the satellite image was taken. The change from scrub to deciduous forest could be an edge effect where vegetation from both categories merges and the resulting reflectance values of the satellite image tend more towards the forest vegetation type. The land cover classification in this area does not follow a set convention with most land cover classes merging into one another or areas being a mixture of two or more land cover types. This could explain the changes observed between rocky, sandy and open ground.

Although a high proportion (35%) of scrub habitat within the study area has shown a decrease (Fig. 3), there are also areas where scrub has been observed to increase. The land use land cover maps indicate that most of these areas of increase border the deciduous forest, and may therefore be a result of growth of vegetation in the absence of any influence from human habitation.

In assessing the potential for using a remote-sensing approach to quantify changes in habitat structure, accurate classification of the satellite images is clearly critical. In the present study, field data employed during the supervised classification and the subsequent accuracy assessment (ground-truth) were obtained in April 2004. The classification of early images is based solely on digital data and the 3½-year gap between the 2000 image and the subsequent ground-truthing could clearly influence the precision of the classification process. As previous research has demonstrated, Jerdon's Courser is associated with scrub, which is associated with a transition between forest and open areas. Although many transition zones are correlated with rapid changes imposed by environmental factors, others are a direct result of human activity (Kent *et al.* 1997). In the use of satellite imagery, drawing boundaries in natural vegetation areas and distinguishing gradual change in community type within the habitat is a complex and difficult task (Fortin *et al.* 2000, Janssen 2000) and can result in inaccuracies in classifying the spectral signatures (Gottschalk *et al.* 2005). In this area scrub tends to be related to the practice or abandonment of agricultural activities. Hence, any classification of scrub vegetation has an element of uncertainty. However, the magnitude and consistency in the direction of change in scrub area strongly suggests that rapid scrub loss is a serious concern for Jerdon's Courser and other species dependent on this habitat.

To an extent, this uncertainty in classification was resolved by using fuzzy classification, which has become an increasingly used tool to deal with spatial uncertainties and ambiguities in ecology (Hunsaker *et al.* 2001). An alternative approach to this problem would be to use a number of satellite images within a narrow time frame to quantify gradual changes over time.

Previous studies have shown that Jerdon's Coursers prefer a narrow range of bush densities within the broader category we defined as scrub in this study (Jeganathan *et al.* 2004). Bush density can be estimated from variation in reflectance values within a single image (Jeganathan *et al.* 2004), but it is likely to be difficult to measure changes in bush density accurately using satellite imagery because of uncontrolled differences between images obtained on different dates.

As a consequence of the rediscovery of Jerdon's Courser, three forest areas within the Cuddapah and Nellore districts have been designated as wildlife sanctuaries (BirdLife International 2001). Community-based conservation and ecotourism have also been suggested as potential ways to increase awareness about this species and to further conservation efforts. However, these plans have yet to be implemented. The land cover maps generated in this study suggested that little scrub loss is occurring in the wildlife sanctuaries at present. The transient nature of scrub habitats means that a certain amount of disturbance is required for its maintenance. Protected areas and sanctuaries allow for regulated levels of human intervention and disturbance while preventing widespread clearance and complete loss of scrub. The designation of more areas as sanctuaries or expanding the existing protected areas may therefore be an effective means of protecting the habitat, at least in the short term. Clearing of scrub was highly visible during ground-truthing for this study, but it was also apparent that this clearance currently stops just outside of the sanctuary border. Maintaining the status and integrity of protected areas and protecting the areas outside them that hold Jerdon's Coursers is likely to be the most effective way of preserving the habitat of this critically endangered species.

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